Naval Surface Warfare Center
Carderock Division
West Bethesda, MD 20817-5700

NSWCCD-CISD–2006/006 April 2007

Ship Systems Intregration & Design Department

Technical Report

Use of Heavy Lift Ship as a Maintenance and Repair Vessel

by

Robert Cullen

Unrestricted Distribution

NSWCCD-CISD-2006/006

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
28-Jul-2006

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*
1-Dec-2006 – 1-May-2007

4. TITLE AND SUBTITLE
Use of Heavy Lift Ship as a Maintenance and Repair Vessel

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Robert Cullen

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)
Naval Surface Warfare Center Carderock Division
9500 Macarthur Boulevard
West Bethesda, MD 20817-5700

8. PERFORMING ORGANIZATION REPORT NUMBER
NSWCCD-CISD-2006/006

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
875 North Randolph Street
Arlington, VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Unrestricted Distribution/Public Release

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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15. SUBJECT TERMS
Heavy Lift Ship, Maintenance and Repair Ship, CISD

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Steve Ouimette
a. REPORT	b. ABSTRACT	c. THIS PAGE	UL	44	19b. TELEPHONE NUMBER *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED			301-227-4219

Abstract

The purpose of this study was to explore the feasibility of using commercially available heavy lift vessels to perform mission support functions. The concept was to use commercially available heavy lift vessels to transport material and equipment to perform a specific function without building a ship dedicated to that specific function. This report describes the use of heavy lift vessels for marine maintenance and repair applications. The objective was to develop a system for ship maintenance and repair that is adaptable to any commercial heavy lift vessel configuration. The feasibility of the designs was demonstrated using 3D-CAD design software and weight and space analysis, which was conducted on three existing vessels with different configurations, available deck area and payload capacity.

Acknowledgments

The author would like to thank Dr. Chris Dicks for his support in compiling this study. Dr. Dicks experience in the Royal Navy with maintenance and repair operations provided valuable insight and assistance and determining the design for this MAR vessel. I would also like to thank Dr. Colen Kennel for his assistance in compiling this study.

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Introduction

Objective

This report describes the work conducted to research and explore the feasibility of using heavy lift ships to serve as marine maintenance and repair (MAR) platforms in lieu of a dedicated maintenance and repair ship. The original proposal was to develop a MAR system that could be adapted to a variety of different heavy lift ships and provide the necessary functions required in a wide range of MAR situations.

Background

The US Navy has explored the use of heavy lift vessels for several applications in recent years. Most notably, heavy lift vessels have been used as ship transports as well as components in sea basing exercises. For example, the MV Blue Marlin was used in the transportation of the USS Cole for repairs after she was damaged in an attack (Figure 1). Heavy lift ships have also been used in Seabase exercises as a transfer point of supplies from cargo ships to littoral boats. Heavy lift vessels provide large working areas as well as the capability to transport heavy and bulky loads while maintaining the ability to change the ship's attitude at will. These characteristics make them valuable assets and potentially allow them to be used as platforms for staging a multitude of operations including disaster relief efforts as well as military staging efforts. Through the use of these ships, a navy may accomplish tasks, which in the past required several specialized ships.

Figure 1: USS Cole transported on Dockwise carrier (www.dockwise.com)

Requirements

The functional requirements for a marine MAR system were developed by:

- Researching land based MAR facilities;
- Researching current Navy MAR vessels;
- Researching current on-board repair capabilities of Navy Ships; and
- Consulting with CISD engineers.

The following list outlines the requirements of the MAR system:

- Provision of accommodation and hotel services
- Provision of storage for MAR equipment and supplies
- Provision of all required over the side services
    - Electrical power
    - High/low pressure air
    - Distilled and potable water
    - Chilled water
    - Hydraulic flush
    - Specialist high voltage services for electric ships
- Ability to receive general and MAR stores
- Ability to safely position MAR capability relative to stricken vessel
- Provision of workshops and material
- Provision of communications
- Provision of transport capability
- Ability to transport personnel, stores, and equipment to and from entitled units
- Provision of Waste Management
- Ability to conform to Maritime Pollution and other anti-pollution regulations
- Ability to carry out structural repair of steel and composite vessels
- Ability to repair combat systems
- Ability to repair sensors and communications equipment
- Ability to conduct underwater MAR operations
- Provision of fire-fighting assistance to stricken vessels
- Ability to handle hazardous materials
- Ability to support conduct salvage operations
- Provision of dry-dock for small to medium size ships

Another set of requirements involves the space and weight requirements of the heavy lift vessels that will be used to transport the MAR system. Three representative vessel types were chosen to use as a basis for MAR system designs including:

- Large load capacity, open deck (similar to M.V. Black Marlin)
- Combination product tanker and heavy lift vessel (similar to M. V. Swan)
- Specialist dock or yacht transport ship (similar to CombiDock 1 & 2)

The rational behind choosing three different types of heavy lift vessels to use as a design basis for an MAR system is that the system should be able to work with a variety of

heavy lift vessels and should not be designed for a specific vessel. This design requirement will allow the MAR system to work with a variety of heavy lift vessels and not be limited if specific vessels are not available. The general characteristics of the three representative heavy lift vessels can be found below in Table 1. Appendices D, E, and F contain schematics of the heavy lift vessels and some vessel characteristics.

Table 1: Indicative Heavy lift vessels and characteristics

Ship	Length of Storage (m)	Width of storage (m)	Deck Area (m^2)	Weight Capacity (MT)	Defining Characteristic
M.V. Black Marlin	178.2	42.0	7484.4	205,821	Large open deck surface
M. V. Swan	126.8	31.6	4006.9	64,110	33,000 m^3 cargo tank
CombiDock	132.6	18.9	2506.1	53,888	Two 350 MT capacity cranes and one 200 MT capacity crane as well as 17,000 m^3 cargo tank

The following sections discuss the MAR systems designed to meet these requirements as well as how these systems are incorporated into three commercial heavy lift vessels.

Concept Description and Evolution of Design

The design of a heavy lift ship compatible MAR system focused on the following core characteristics:

- Adaptability to different MAR situations and requirements
- Ability to function in conjunction with a variety of commercial heavy lift vessels
- Ability to utilize system for applications other than MAR

Initially, several different scenarios and designs were explored to satisfy these core characteristics. From the beginning, the MAR system was designed to be operated using reconfigurable 20 ft ISO storage containers. The decision to use containers as a basis for the MAR system was made because they are adaptable to a variety of different applications, can be easily transported to different locations, and can be stored compactly. The containers also provide a sheltered working area for MAR crew to perform their activities. There are several companies that produce specifically designated container units for crew housing, water treatment, machine shop use, etc. The MAR containers would be stored in a port until required for a MAR operation. When the need arises, a heavy lift vessel will be chartered to transport the MAR containers from storage to the required location.

The next step in the design process involved deciding how these containers would be arranged to perform their function on a heavy lift vessel. One option that was explored involves building the MAR platform directly to the deck of the heavy lift vessel. This option would involve welding or fastening each container to the heavy lift vessel deck when the ship arrived at the storage area. However, it was decided that this was not the best option for several reasons. First, the time to deploy the MAR capability would be extensive because once the heavy lift ship reached the port where the MAR containers are stored, time would have to be spent attaching each container to the deck of the ship. Also, not only does attaching the containers to the deck require a lot of time, but it would also involve modifying the heavy lift deck, and any modifications made to the deck would have to be removed at the end of the operation. This aspect could come at great cost to the Navy depending upon the modifications that are required. Another disadvantage of building the MAR platform directly on the heavy lift ship is that it requires the Navy to charter the ship for the entire operation, rather then just for transport to and from the operation.

Another design that was explored and eventually adopted for this report involves permanently mounting the MAR containers onto free floating platforms that would be transported by a heavy lift vessel. The idea is that when an MAR need arises, a heavy lift ship will be chartered to transport the MAR platforms to the required area. While the heavy lift vessel is in transport to the MAR storage port, the MAR platforms can be assembled and remain waiting for the ship to arrive. The containers would either be welded or fastened to the floating platforms. Once the vessel arrives, it will submerge and place the waiting MAR platforms on its deck. The platforms would then be moored to the deck and transportation would begin to the MAR operation. This design eliminates the time required to modify the heavy lift ship and also would avoid much of the cost associated with modifying the ship. This design also only requires the heavy lift vessel to serve as transport to and from the MAR operation and if necessary, the free floating platforms can perform their MAR function in the absence of the heavy lift vessel.

Two systems were researched to serve as the free floating MAR platforms including commercially available barges and Mobile Causeway Sections currently in use by the Navy. The following paragraphs discuss in detail the use of these systems as MAR platforms.

Barges as MAR Platforms

Initially, the design process involved researching commercially available heavy lift vessels to determine their characteristics as well as to give boundaries for the design. The Center for Innovation and Ship Design had previously worked with the heavy transport shipping company Dockwise B.V., and as a result research was done on their fleet to get a representation of commercially available heavy lift vessels. While in the process of researching Dockwise and its fleet, one of the transport operations performed by the company was particularly interesting and relevant. The operation involved using the MV Blue Marlin to transport power barges from Singapore to Brazil, which can be seen below in Figure 2 [2]. Once the power barges were transferred, they were offloaded and supplied power to land based applications via a floating, mobile unit. This operation led to the concept of using floating barges as MAR platforms and transporting them to their required destination using heavy lift vessels.

Figure 2: Blue Marlin transporting power barges (www.dockwise.com)

The concept of using barges as MAR facilities has also been explored and implemented by the US Army Corps of Engineers (USACE). USACE Nashville District operates a MAR barge called the USACE Crane Barge Brinkley, which can be seen below in Figure 3. This barge is approximately 78 m long and 17 m wide, weighs approximately 900 MT, and can store approximately 5,000 gallons of potable water. In addition, the barge is outfitted with a machine shop containing an overhead crane, drill press, lathe, band saw, vertical mill, and fabrication/welding area [4].

Figure 3: USACE Crane Barge Brinkley (www.nap.usace.army.mil)

The idea is to take the use of barges as MAR platforms and the use of heavy lift ships as barge carriers and combine them to provide MAR services for the Navy without building a dedicated MAR vessel. The concept involves building MAR platforms onto commercially available barges. These barges would be able to service all MAR requirements and would be stored in a port. When necessary, a commercially available heavy lift vessel would be chartered to transfer the barges to their required destinations. After the MAR barges have reached their destination there are several options:

- The barges remain and operate on the heavy lift vessel;
- The barges are offloaded and moored alongside the heavy lift vessel to provide dry dock space; or
- The barges are offloaded and towed to a sheltered environment to allow the heavy lift vessel to transport other material.

Depending on the situation, either one of the three above configurations could be utilized. For example, in a case such as the transport of the HMS Nottingham when she ran aground, the MAR operation involved the heavy lift vessel Swan acting as a floating dry dock so repairs could be made while the ship was on route back to its home port. In this case, there would not be enough space on the heavy lift vessel for the MAR barges and the large ship. As a result, the MAR barges could be offloaded, moored to the side of the heavy lift vessel, and provide MAR operations to the dry docked ship. A 3D representation of this example is shown in Figure 4. In the case of smaller ships, the floating dry dock service can be provided with the barges still on the heavy lift vessel.

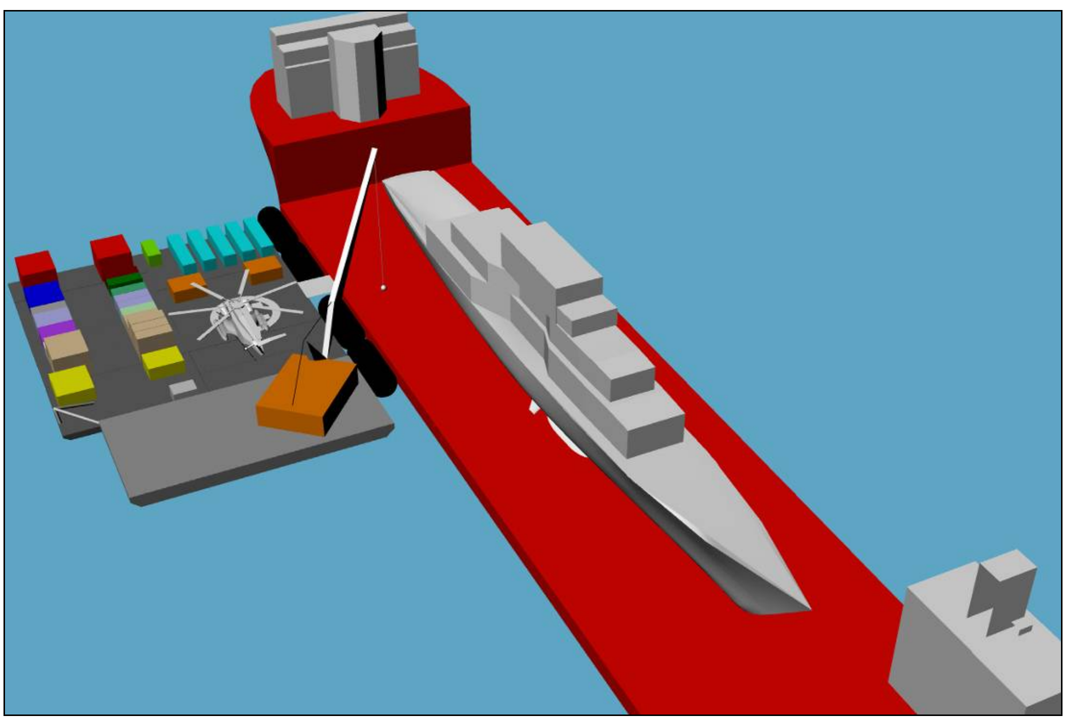

Figure 4: MAR system moored to HLV with large ship dry docked

Barge Design Concepts

There are many commercially available barges that would satisfy the requirement of being able to support an MAR platform. For example, Norfolk Barge Company builds a flat deck barge that is 12.192 × 6.096 × 1.219 m, weights 25.85 MT, and can support a weight of 22.7 MT. The barge also has the capability of storing potable water inside coated interior tanks [3]. An image of a similar size barge can be seen below in Figure 5.

Figure 5: Norfolk Barge Co. flat deck barge (www.colonnaship.com)

There are several advantages of using barges as MAR platforms. One of the main advantages is that the barges can store liquids in treated holding tanks. The ability to store liquids is a valuable asset because many MAR operations require large amounts of water and POL. As a result, using barges as MAR platforms offers the capability to store these essential liquids without taking up deck area with large holding tanks.

Another advantage of using barges as MAR platforms is the fact that they can operate independently of the heavy lift vessels that transport them. In the case when barges are not used and the MAR systems are placed directly on the heavy lift vessel's deck, the heavy lift vessel is required to stay in the area of the damaged ship for the entire operation. However, if barges were used as MAR platforms, heavy lift ships would only be required for transportation to and from the objective. In the case where the heavy lift vessel cannot remain in the operational area, the vessel could transport and offload the MAR barges, perform other operations unrelated to the MAR, then return and retrieve the MAR barges when the repairs of the damaged ship are completed.

The use of barges as MAR platforms also offers the advantage of flexibility if the MAR platforms are not built permanently on the barges. If the MAR systems are separate from the barges and stored in land based facilities when they are not being used, the barges can

be used for other applications such as disaster relief. In the case where a MAR vessel is required, the MAR systems can be placed on the barges using dockside cranes while a heavy lift vessel is in transit. Once the heavy lift vessel arrives, the barges will be ready for transport to the damaged ship. This aspect of the MAR barges saves time in situations where time is critical to the survival of a damaged ship.

One disadvantage of using barges as MAR platforms is the sea keeping performance of the barges. Most barges are operational in conditions up to sea state 2, which limits the situations when the barge can operate and perform its function. One way to expand the situations in which the barges can work would be to have them take advantage of the sea keeping of the heavy lift vessel and remain on the vessel throughout the MAR operation. However, this advantage is limited because it requires the heavy lift vessel to remain with the MAR barges throughout the repair and limits the use of the heavy lift ship as a dry dock to smaller vessels.

Mobile Causeway Sections (MCS) as MAR Platforms

An alternative to using barges is utilizing the mobile causeway system as MAR platforms. The mobile causeway system (MCS) consists of creating a flat, floating work area using Intermediate Modular Causeway Sections (IMCS). These sections can be fitted together to form a work area of different sizes that can be broken down into smaller, easier to store and transport sections. There are four types of IMCSs; center modules, and left, center and right end rake modules. The center modules are 8 ft wide, 40 ft long, and have a depth of 4-6 ft. Each center module has two 23 MT capacity lifting shackles enabling them to be moved around by a crane. The approximate weight of each center module is 10 MT and can be seen below in Figure 6.

The left, center, and right end rake modules are all 8 ft wide, 20 ft long, and have a depth of 4-6 ft. Each of these modules has one 23 MT capacity lifting shackle enabling them to be moved by crane and the weight of each section is approximately 6 MT. The end rake modules can be seen below in Figure 7.

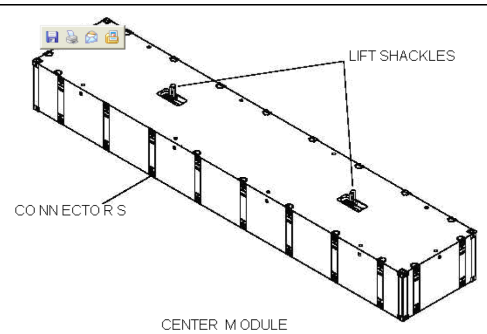

Figure 6: Center Module

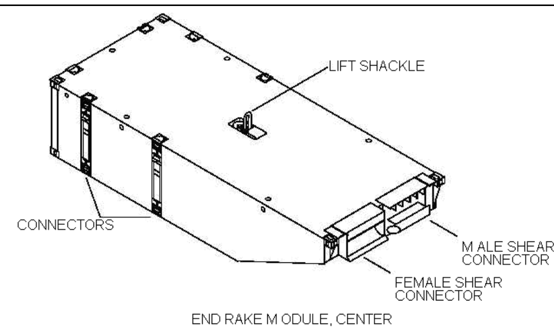

Figure 7: End Rake Module

The total MCS consists of two left end rake modules, two center end rake modules, two right end rake modules, and three center modules. The total MCS is 24 ft wide, 80 ft long, has a depth of 4-6 ft and weighs approximately 66 MT. The MCS is designed to support the weight of a 60 MT Abrams tank. An assembled MCS is shown in Figure 8.

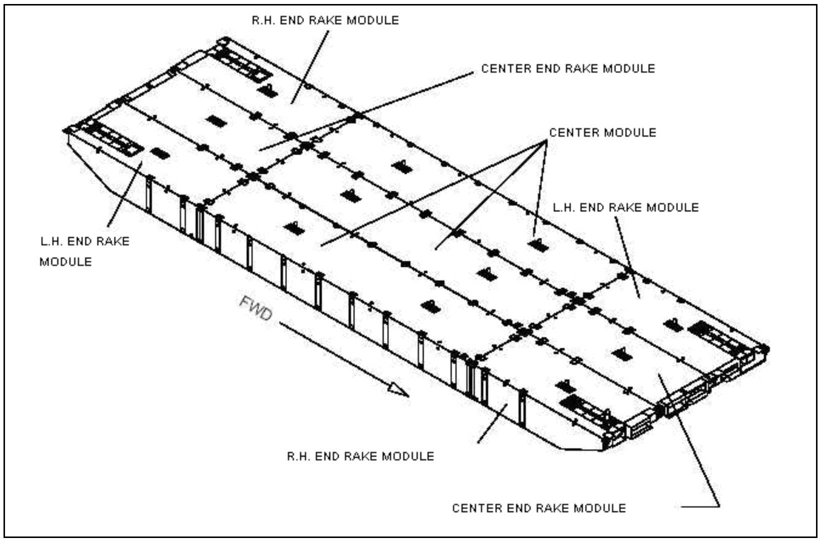

Figure 8: Assembled MCS Unit

The MCS system would work in similar way to using barges as MAR platforms and share some of the same advantages. Both platforms offer flexibility in their use, can be used for other operations if necessary, and allow MAR operations to take place independent of whether the heavy lift vessel can remain in the operation area or not. Both platforms are also not self-sufficient and require the use of a tugboat for movement. In the case of the MCS units, a specialized MCS unit called a Warping Tug is used to move and position the individual sections. The Warping Tug is an MCS unit that is fitted with water jets as well as a crane. A representative drawing of a Warping Tug can be seen below in Figure 9.

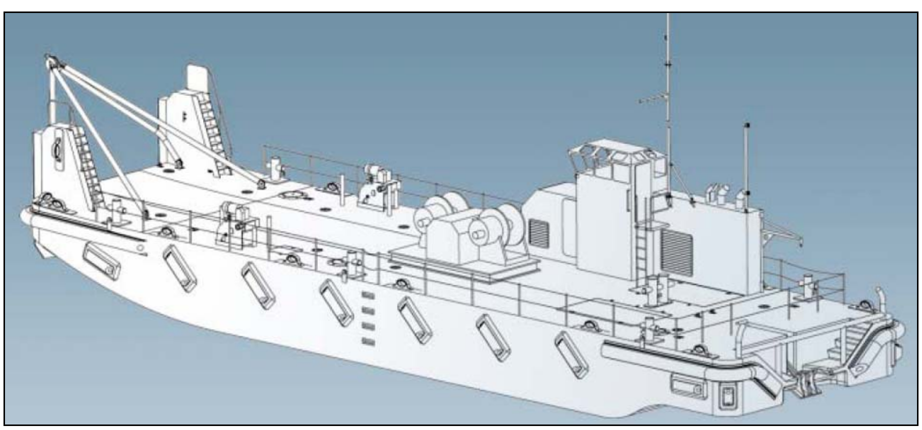

Figure 9: Warping Tug is a specialized MCS unit used for positioning other MCS units

One of the advantages of using MCS units instead of barges is that the MCS units are lighter and are designed to fit inside a standard 40 ft ISO container. The total MCS can be broken down into three smaller sections that are 80 ft long, 8 ft wide, and have a depth of 4-6 ft. Each of these smaller sections can then be folded up and placed into a 40 ft ISO container. The advantage of this capability is that it allows for easy transport and storage of the MCS units when they are not in use.

Another advantage of using MCS units rather then barges is the fact that MCS units offer more flexibility in the size of the work area that can be assembled. The smaller IMCS units can be assembled in different manners to allow for a workspace that is not limited to the 24 ft wide, 80 ft long standard MCS configuration. An example of this flexibility can be seen in Figure 10 below. This figure shows the use of MCS units as a RO/RO discharge facility configuration to allow for the optimum deck space to transfer vehicles from a larger ship to a smaller ship [5].

Figure 10: MCS units acting as RO/RO discharge facility

One disadvantage of using MCS units instead of barges is that MCS units do not have treated liquid storage tanks as barges do. As a result, more deck space will need to be devoted to store the large amounts of POL and water that are required for MAR operations. However, this disadvantage is not that great because there is a negative aspect to having built in storage tanks. Whether the liquids are stored above deck or in built in storage tanks, the barge can still only support a certain load. As a result, barges with storage tanks are not any more space efficient because they cannot store as many supplies on deck with storage tanks filled with liquid. Another disadvantage of the MCS system, similar to the barge system, is the fact that the MCS system can only be operated in conditions up to sea state 2 [13]. As a result, both options are limited in the working environments in which they can function.

MAR Components

The process of generating the systems for the heavy lift vessel compatible MAR system involved researching the US Navy's Battle Force Intermediate Maintenance Activity (BFIMA) program as well as interpreting the requirements in the previous section, and researching current U. S. Navy MAR practices. The purpose of the BFIMA program is to ensure the fleet is able to provide timely, high-quality repair service for Navy ships [15]. Training for this program includes the following capabilities:

- Air compressor repair
- Air conditioning and refrigeration repair
- Valve repair
- Boiler repair
- Cam pump repair
- Centrifugal pump repair
- Diesel engine repair
- Electric motor repair
- Electrical equipment repair
- EPA refrigerant handling
- Hose repair
- Heat exchanger, cooler and distilling plant repair
- Hydraulic systems repair
- Machinery shaft alignment
- Oxygen –nitrogen producer repair
- Rigging repair
- Sheet metal repair
- Structural repair

Based on these required maintenance capabilities, as well as current U. S. Navy MAR practices and the requirements outlined at the beginning of this paper, it was determined that the MAR system requires the following systems and associated stores:

- MAR Crew Housing/Accommodations
- Communications
- Ship Salvage
- Pollution Control
- Machine Shop (Structural Shop and Pipe Shop included)
- Electrical Shop
- Material Storage
- Helicopter Pad
- Crane Barge
- Composite Shop

The motivating factors in the design of the MAR systems to be placed on the MAR platforms were space and ease of transportation. As a result, it was decided to focus on the concept of using ISO containers as storage devices as well as for work areas. There

are several advantages to using ISO containers including the fact that they provide a sheltered working environment and can be easily transported by current Navy capabilities. The following sections outline the background of each system as well as the process for determining the requirements of each system. Also, a table listing the different systems and the services they provide can be found in Appendix B.

MAR Crew Housing/Accommodations

The first system that is necessary in all MAR operations is a system to house the MAR personnel and crew. These accommodations must include at a minimum sleeping quarters, cleaning facilities, restrooms, and areas to prepare food. They also must provide these services for the estimated 30 personnel that would be necessary to carry out an MAR operation.

One of the most space efficient and storage/transportation efficient methods to provide these accommodations is in retrofitted ISO containers. The U. S. Navy has standard 20 ft ISO containers converted into housing units for use in emergency pollution control operations. The Navy ISO containers can each house seven people and include bunks, lockers, lights, a kitchenette or microwave, a portable water tank, a refrigerator, a heater, and an air conditioner [9]. Each unit can be supplied either by excess power from the heavy lift ship or by additional 30 kW generators. An internal and external view of the housing container can be seen below in Figure 11.

Figure 11: Internal and external view of converted 20 ft ISO container for housing

There are several commercial companies that also offer different configurations of housing ISO containers. One configuration involves designating one ISO container specifically for bunks, one specifically for showers, and one specifically for restrooms. Either configuration will work as long as there is enough housing to support the MAR personnel.

In order to calculate the amount of accommodation space that would be required to support an MAR crew, a disaster relief spreadsheet developed by Jennifer Gardner was adapted for MAR personnel. The spreadsheet calculates the amount of housing units,

restroom/shower facilities, waste management facilities, and food/water required to support a certain amount of people for a certain amount of time. Each of these provisions is stored inside a standard 40 ft ISO container and there is a specifically designed container for personnel bunks, showers/restrooms, waste management, and food/water storage. For the MAR analysis, the amount of necessary accommodations was calculated estimating a crew of 30 people operating over a period of ten days. The results of the accommodations analysis can be seen in Appendix C.

Communications

Another important aspect of an MAR operation is the ability to communicate with engineers and authorities who are not available for on-site consultations. These personnel provide valuable resources and insight into MAR processes and can often provide analysis that is not directly available to personnel performing the maintenance and repair work. An example of how important communication is during an MAR operation is the repair of the HMS Nottingham. During the initial inspection of the ship, there were constant communications between the on-site engineers and engineers in England to try and determine the stability and sea worthiness of the ship [7].

In order to satisfy the communications requirement of an MAR system, another piece of equipment currently in use by the U. S. Navy will be utilized. The U. S. Navy currently has equipment in reserve to be used in emergency pollution control situations. One resource that is stored is an 8 ft long, 8 ft wide, and 8 ft high trailer equipped with communications devices. The communications system operates using a geostationary International Maritime Satellite Organization satellite to communicate with onshore facilities. As a result, personnel at the MAR site have access to worldwide communications [9]. An internal view of the communications trailer can be seen below in Figure 12.

Figure 12: An internal view of a communications trailer

Ship Salvage

The ship salvage system is an integral part of MAR operations and can provide valuable functions and services including:

- Underwater repair
- Flotation/ballasting of damaged ships
- Water purification
- Removal of water from flooded compartments
- Compressed air
- Lighting

The above list is based on the Emergency Ship Salvage Material System (ESSM) operated by the U. S. Navy. The ESSM is a combination of bases and storage facilities that provide ship salvage equipment on an emergency basis [9]. The catalog provides a list of equipment that is stored in bases around the world to support emergency salvage operations. The catalog was evaluated and certain equipment was chosen to give a representation of what supplies would be necessary to conduct a salvage operation. The size and weight of each piece of equipment was recorded and used in the weight and space analysis located in Appendix C.

In order to conduct underwater repairs of a damaged ship, it was determined from the ESSM that the MAR system would require dive equipment as well as underwater welding equipment. For this study, the required equipment for conducting diving operations includes a control console, diesel compressor, air tanks as well as hoses. The required equipment is based on the Operation and Maintenance Manual for the U.S. Navy Lightweight Dive System (LWDS), which should be consulted for more specific equipment as well as instructions on the setup and use of the equipment. A representative image of the arrangement of a LWDS can be seen below if Figure 13. The sizes and weights of the diving material were recorded and used in the weight and space analysis located in Appendix C.

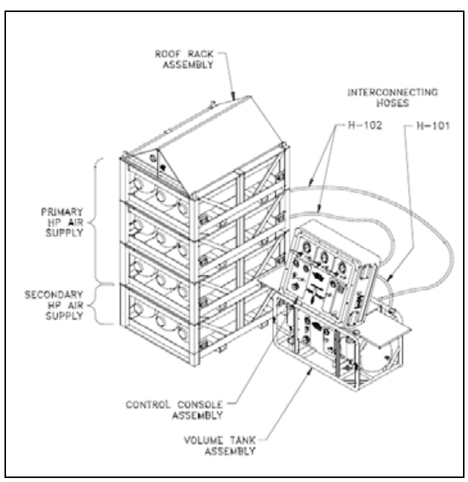

Figure 13: Representative image of LWDS system

The following table outlines the equipment that will be used to perform the functions of the ship salvage component of the MAR system. This list is just a representative list and may vary depending upon the specific MAR requirements. The sizes and weights of the diving material were recorded and used in the weight and space analysis located in Appendix C.

Table 2: Ship salvage functions/services and the equipment required

Ship Salvage Function/Service`	Equipment
Underwater Welding	Provided by a diesel arc welder. This service will work in conjunction with the dive equipment.
Flotation/ballasting of damaged ships	Provided by a salvage bag
Water Purification	Provided by a reverse osmosis water purification unit
De-flooding	Provided by submersible pumping system
Lighting	Provided by 120 V light stand
Compressed air	Provided by 600 CFM air compressor system

Pollution Control

Pollution control is another essential component of an MAR system. A damaged ship may leak hazardous materials into the environment and it is important to control the spread of these materials. The Emergency Salvage Material System was consulted in order to develop a representative list of requirements and equipment for pollution control. The system has an entire manual dedicated to pollution control in salvage operations that lists the equipment available to carry out such operations. Based on this manual, it was determined that at a minimum the following equipment would be necessary:

- Oil Containment Boom
- Portable Fire Fighting
- Low Pressure Fenders
- Command Van
- 290k-Gallon Storage Bladders

The oil containment boom is important for controlling any POL that may be leaking from a damaged vessel. Once the oil is contained, the pumping system used in the ship salvage section can be used to pump the spilled materials into 290-k gallon storage bladders for transport to a disposal facility. The command van is used as a center to direct all MAR operations and the low pressure fenders are used when mooring the MAR platforms next to a damaged ship or next to the heavy lift ship. An important attribute of the pollution control materials is that each of these materials can be stored in its own standard 20 ft ISO container. The sizes and weights of the pollution control material were recorded and used in the weight and space analysis located in Appendix C.

Workshops

In order to provide MAR services for all of the equipment, structures, and services of a Navy ship, several workshops are required. These workshops include a machine shop, electrical shop, and composite shop. In order to establish the facilities necessary to support MAR operations, commercial land based MAR facilities were studied as well as current at sea facilities. The following paragraphs describe the background and setup of each of the workshops that will be included in the MAR system.

Machine Shop

One of the more important workshops included in the MAR system is the machine shop. The machine shop offers the ability to perform several operations that are essential to the repair of piping within the ship, rigging equipment, metal structures within the ship, as well as equipment such as compressors and pumps. Instead of having a separate pipe shop and a separate structures shop, these two shops will be incorporated into the machine shop because all three would use relatively the same equipment. The equipment necessary for a machine shop in an MAR system was established by using the machine shop at the University of Nevada, Las Vegas as a model. Based on this model, it was determined the machine shop would require a lathe, mill, band saw, plasma cutter, hydraulic press, drill press, welding generator, cutting torch, and cables. Once this list was determined, representative machines were researched to determine the size of the shop as well as the approximate weight of the shop. In order to make the machine shop more realistic, 1 m was added to the length and width of each piece of equipment to allow for space to operate the equipment.

As a result of including all of this equipment, the MAR system provides the ability to perform welding operations as well as metal work to service a damaged ship. Similar to the other aspects of the MAR system, all of this equipment will be stored and operated in standard 20 ft ISO containers to provide shelter as well as ease of storage and transportation. The sizes and weights of the equipment for the machine shop were recorded and used in the weight and space analysis located in Appendix C.

Electrical Shop

Navy ships are becoming increasingly technologically advanced with electronic warfare, navigation, and communication systems. The operation of these electronic systems is vital to the ability of these ships to carry out their missions and objectives. As a result, a MAR system must have the capability to maintain and repair these complex electronic systems. The equipment necessary to service the electronic hardware on a ship includes, but is not limited to computers, soldiering equipment, oscilloscopes, wiring, resistors, capacitors, transistors, and inductors. Although the electrical shop equipment is not as robust as the equipment necessary in the machine shop, the shop does require a sufficient working area as well as storage for sensitive electrical equipment. There are several companies that produce standard 20 ft ISO container workshops that would be ideal for

the electrical shop. An example of an ISO workshop from Sea Box Inc. can be seen below in Figure 14.

Figure 14: 20 ft ISO workshop (http://www.seabox.com/id-31)

Composite Shop

Along with having increasingly sophisticated electronic systems aboard, Navy ships are also increasingly using composite materials. Composites offer a material that is lighter than steel but can also exhibit high strength properties. This lighter material allows Navy ships to become faster and consume less fuel then previous steel ships. However, the use of composites does require special MAR services that cannot be handled by a traditional machine shop. In order to establish the specifications for the MAR composite shop, research was conducted into comparable land-based composite shops as well as composite MAR procedures/processes. The focus of the research was primarily on a document published by Hexcel Composites on composite repair. Based on this document, it was determined that the composite shop should include a hot bond unit, compressed air, vacuum pump, power supply, mold making material, and heater blankets. An arrangement of these materials can be seen below in Figure 15.

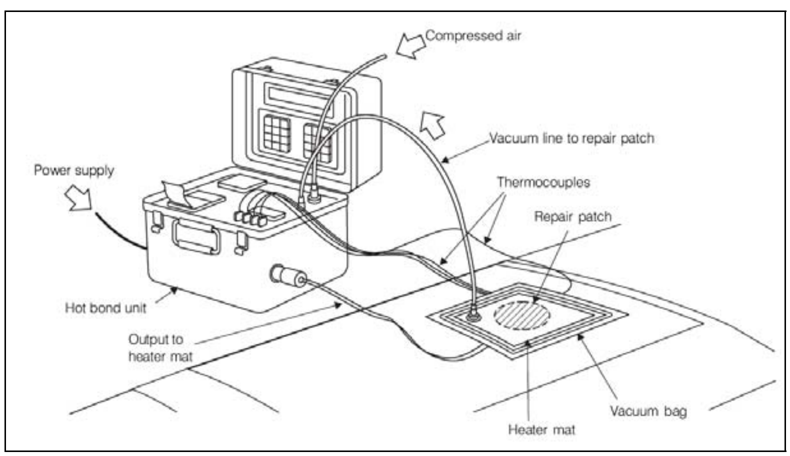

Figure 15: Representation of composite repair setup (http://www.hexcel.com/)

In order to determine the space and weight requirements of the composite shop, research was conducted on commercially available equipment comparable to the list of equipment in the previous paragraph. The results of this research can be found in Appendix C. Based on this research, it was determined that a standard 20 ft ISO workshop container similar to the electric shop container would be suitable for the composite shop. The

advantage of the container is it provides an enclosed working environment which is essential due to the health hazards of breathing in materials used in composite fabrication.

Material Storage

Designing a system for material storage in an MAR operation creates a challenge due to the fact that each MAR operation will require a different amount and type of materials. As a result, the storage system design is based on the use of standard 20 ft ISO containers. The use of standard storage containers allows different amounts and types of materials to be carried depending upon the specific MAR mission. The goal of this section is to outline assumed material storage requirements for a very general MAR operation. The material discussed in this section is only a representation of what material may need to be stored and depending on the specific MAR operation this material may be different. Discussions with CISD personnel as well as research into material storage on current navy ships were used to determine a set of basic required stores. Based on this information, the following materials will be stored for the general MAR case:

- Food/Water
- Bulk Steel
- Timber
- Lubricants
- Paint
- Fork Lifts
- Diesel Generators
- Concrete
- Repair Pipes
- Composites

The following paragraphs outline the background of the material selection above. The numbers used for space and weight representations for this section are estimates and in some cases assumptions. These numbers and material choices will change based on the specific MAR operation. Also, the numbers are based on performing MAR on a ship similar in size and class to the USS Cole.

One of the most important materials that are required for an MAR operation is food and water for the MAR crew. In order to calculate how much food in water would be required a spreadsheet that calculates the supplies required for disaster relief was modified for an MAR mission (Gardner). The spreadsheet calculates the number of 40 ft ISO containers of water and food that are necessary based on the amount of people as well as the time frame the supplies will be required to support. This study assumed for a general case that an MAR crew of thirty personnel would be operating for 10 days. The results of the spreadsheet analysis and the amount of containers that are necessary can be found in Appendix C.

The next material that will be required in large quantities for an MAR operation is steel. The steel will appear in several different forms including, but not limited to, I-beams, flat sheets, and specialty items. For example, during the heavy lift transport of the USS Cole,

the salvage team used approximately 12 300mm×19mm/300mm×11mm steel I-beams to keep the ship from rolling during transport [10]. The steel stored for a general MAR application will be used to support creating a dry-dock for a damaged ship, structural repair on a ships hull, and general equipment repair. The amount of steel that will be stored was estimated to be 10 tons and is based on the MAR experience of CISD personnel. As with all other materials that will be stored in the MAR system, the steel will be stored in 20 ft ISO containers. The number of containers necessary to store this amount of steel was determined by calculating that the steel appears as 1in. thick flat plates that are in 8 ft by 20 ft sections. This assumption provides a conservative estimate and should allow for the space necessary to store other forms of steel.

Timber is another material that is important in MAR operations. Timber has many uses on board a ship, but is primarily used when shoring of the hull is required or in temporary dry dock operations. The amount of timber that is required will vary depending on the MAR operation. For this study, the amount of timber necessary was calculated using the case study of the USS Cole heavy lift transport written by R. G. Wasalaski from Naval Sea Systems Command. The purpose of the timber used in this case was to support the USS Cole while on the heavy lift ship MV Blue Marlin. The size and number of pieces of timber used can be found in Appendix C. Similar to the other materials, the timber will be stored in 20 ft ISO containers and accessed should a dry docking situation arise. Storing material in these containers is important because it allows for storing large blocks for dry docking operations as well as smaller pieces for hull repair and shoring.

Two other materials that will be stored within the MAR material storage area are paint and lubricants. Lubricants are essential to the maintenance of machinery within a ship and paint is essential in maintaining the integrity of the ship’s hull. The amount of paint and lubricants that would be required for an MAR operation was calculated using the Ship Design Data Book provided by senior CISD engineers. This book calculates space and weight data, logistics data, engine room layouts, and payload data required in the design of a ship based on the size of the ship. The amount of paint and lubricants for this study was based on how much of these materials would be required in the design of a ship similar in size to the USS Cole. The results of this analysis can be found in Appendix C. Similar to the other MAR materials, the paint and lubricants will be stored in 20 ft ISO containers.

Forklifts are also essential material for this MAR system. The forklifts provide a way of moving equipment and materials around the MCS units without relying on the crane barge. The size of the forklift is based on a 4 MT capacity forklift built by Nissan and is included in the weight and space analysis. A picture of a representative forklift can be seen below in Figure 16. This size forklift works well with the MAR system because there are not many items that might have to be moved larger than 4 MT. In the case where a larger item must be moved, the crane barge shwon in Figure 19 can be used. The forklifts will be stored in ISO containers for transport similar to the other materials.

Figure 16: Example of a forklift (www.nissanforklift.com)

Another piece of equipment that will be stored in the MAR material storage system is a 30 kW generator. Although the heavy lift vessels do provide power to service their cargos, it is important to have independent sources of power for the MAR systems. As described in previous sections, due to the ability of the MCS units to float, in a situation where the heavy lift vessel cannot remain in the area after transporting the MAR systems, these systems can still perform their duties alongside the damaged ship. Storing 30 kW generators gives the option of performing this operation. The generators that were used for the weight and space analysis are based on standard generators that are part of the ESSM program discussed previously and can be seen below in Figure 17. They will be stored in 20 ft ISO containers for transport and can be moved to the necessary destination upon arrival at the damaged ship either by fork lift or by crane.

Figure 17: ESSM 30 kW Diesel Generator

The final two materials that will be stored for this MAR system are spare pipes and composites. The amount of each of these items was difficult to determine because they are both depend on the specific MAR operation. If the hull of a ship is being repaired and there are no damaged pipes, then spare pipes are not needed. Also, if the ship does not have any composite parts on board no composite material will be needed. A representative amount of each of these materials was determined through discussions with senior CISD engineers. The amount of composite material was assumed to fill one standard 20 ft ISO container. The amount of spare pipes was assumed to be the amount of 20 ft long, 1 in diameter steel pipes that could fit in a 20 ft storage container. Ultimately, however, the amount of each of these materials depends on the MAR mission that is undertaken.

Helicopter Pad

A helicopter pad is essential for MAR operations because it provides a way of receiving emergency MAR supplies and personnel. In order to estimate the amount of space needed as well as the load of a helicopter, a standard Sikorsky CH-53E Super Stallion was chosen as a model. This particular helicopter provides heavy lift capabilities for the Navy and Marine Corps [11]. The landing area for the helicopter will consist of two MCS units connected together. This will allow the helicopter to land and deliver materials even without the large deck provided by the heavy lift vessel.

Figure 18: CH-53E Super Stallion heavy lift helicopter (www.wikipedia.com)

Crane Barge

One essential piece of equipment for any MAR operation is a heavy lift crane. A crane provides the ability to transport damaged and repaired equipment from the MAR platform to the damaged ship. It also provides crane access in the event that the cranes built into the heavy lift ships are not available or cannot perform the desired task. In order to accomplish this task with this MAR system, it was decided that a crane barge would be used. A crane barge is a crane located on a barge that can be transported to different locations to perform its function. This choice goes along with the use of barges or MCS units as the basis for MAR systems and allows the crane to be transported via heavy lift ship to the desired location. In order to establish size and weight characteristics to be used in this study, a representative US Army Corps of Engineers barge derrick was

chosen as a model. This barge has a load capacity of 100 MT and can be seen in Figure 19 below. The barge does not have its own propulsion system and would need to be positioned via a tugboat.

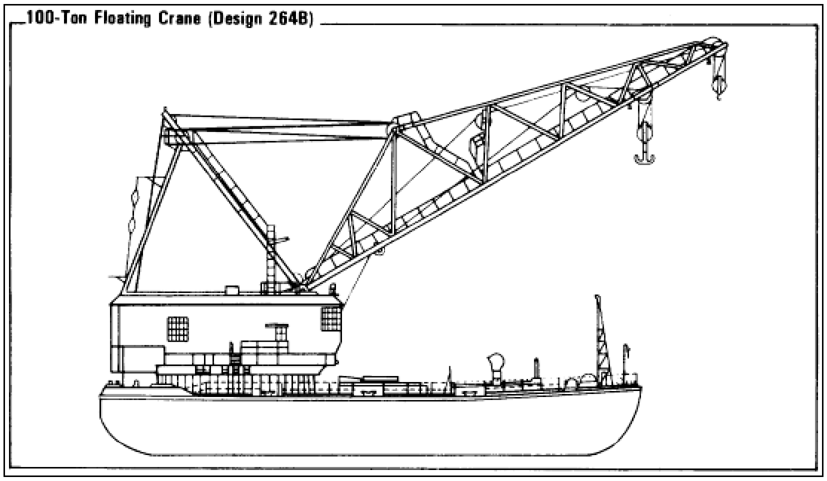

Figure 19: USACE Crane barge derrick (www.globalsecurity.org)

Space and Weight Analysis

The space and weight analysis is based on the data tabulated in Appendix C. In order to establish the space and weight requirements of each of the components of the MAR system, research was done into the components and representative equipment lists were established. The length, width, weight, and number of each component of the MAR system was recorded and then used to calculate the number of ISO containers that would be required to store the components. The number of required MCS units was calculated based on the number of ISO containers and the weight of the containers. The result shows that approximately 56 ISO containers and 14 MCS units will be required to support the MAR system. Two MCS units are included in this number to account for the space required for helicopter access as well as one unit for a Warping Tug and two units for open deck space. Once these parameters were determined, calculations were performed on the total weight and space of the system to ensure that the various heavy lift vessels could support the MAR system loads. The results show that the total weight of the MAR system is approximately 2900 MT and the total deck area is approximately 4250 m^2.

All three representative heavy lift vessels can easily support the total load of the MAR system. The total space required by the MAR system can only be supported by the MV Black Marlin and exceeds the capacity for the MV Swan and CombiDock ships. However, due to the design of the MV Swan and CombiDock, several components of the MAR system are already included in the heavy lift ship. For example, the CombiDock has 3 several hundred MT capacity cranes that can be used to replace the barge crane. Also, the option of dry docking a ship and mooring the MAR system to the CombiDock is not an option because of the high sea walls on the ship. Therefore, to total area

required for the MAR system without the barge crane and the two MCS designated for deck space is approximately 3000 m^2, which is well within the CombiDock design limits. The same is true for the MV Swan; without the MCS units used for deck space the MAR system is well within the design limits of the ship.

Total Ship Model/Architectural Arrangement

The purpose of this section is to outline the design of an MAR system for two heavy lift vessels; the MV Black Marlin and the CombiDock. The designs consist of models or the MAR components using 3-D images as well as reasons for choosing the specific designs. The idea is to show that the MAR system developed in this paper is adaptable to different heavy lift ships and different MAR missions.

The table below lists the different materials stored in ISO tables and the corresponding color that they appear in the CAD drawings.

Table 3: Color coding of ISO containers in CAD drawings

(cyan)	Housing*
(green)	Communication
(orange)	Ship Salvage
(yellow)	Polution Control
(blue)	Machine Shop
(blue)	Structural Shop
(blue)	Pipe Shop
(dark red)	Electrical Shop
(lavender)	Bulk Steel
(red)	Food/Water
(sea green)	Composites
(peach)	Timber 1
(peach)	Timber 2
(purple)	Lubricants
(purple)	Paint
(light green)	Fork Lift (4 MT capacity)
(grey)	Concrete
(white)	30 kW Diesel Generator
(lavender)	Pipes
(dark green)	Composite Shop

MV Black Marlin

The first total ship model is constructed using the MV Black Marlin as a basis. The dimensions of the MV Black Marlin can be found in Table 1. The advantage of using the MV Black Marlin for MAR operations is that it has a large, open deck space to accommodate the different MAR services. Also, the large deck space allows for the use of the deck as a temporary dry dock with the MAR platforms moored to the side of the ship. A disadvantage of this open deck space is that the MAR crew members are exposed to the elements while performing their operations because the ship does not have any side protection. However, this problem is partially eliminated by using the ISO containers as workspaces. Another disadvantage of the MV Black Marlin is that it does not have large

tanks for storing POL or potable water. As a result, some of the open deck space that could be used for MAR operations is required to store these liquids.

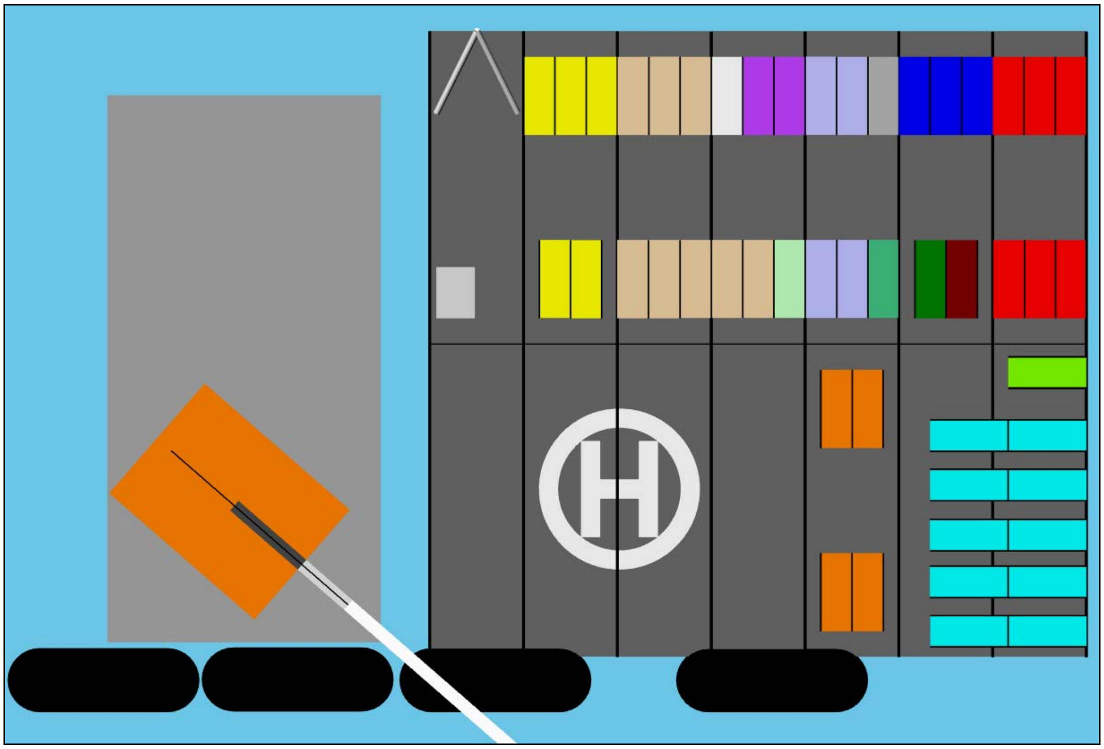

Figure 20: Top view of MAR system arrangement on MV Black Marlin

An important aspect in the design of an MAR system is the arrangement of the individual MAR components. Due to the large open deck of the MV Black Marlin, the arrangement of the different MAR systems can be fairly spread out to provide adequate working spaces. The arrangement is designed to store components that are dependent on one another close to each other to allow for easy access. The arrangement for the MV Black Marlin can be seen above in Figure 20. The housing and communications containers are stored on the same two MCS units to allow the MAR crew easy access to the communication equipment. The food/water will be stored adjacent to the housing and communications MCS to allow for easy access to food supplies. Also in the general area of the housing accommodations are the workshops. The workshops are all located on the same MCS because some repairs will require using several workshops and it is convenient if they are all in the same area. For the same reason of convenience, the repair supply materials are located directly next to the workshop MCS units. Using this arrangement allows for easier transport of the raw materials to the workshops, especially in the case where large quantities are being moved. The salvage equipment is located near the edge of the system because many of the components require unimpeded access to water. An example of a component with this requirement is the underwater engineering system. The crane and helicopter pad are located near the end of the system because they require the most space to operate. A large area is left in this area to allow for helicopter landings, as well as to allow for the crane to place materials to be transferred to other sections of the MAR system by forklift. The most important

characteristic of this design, however, is that because the system is a modular system, the arrangement of the deck can be changed based on the MAR situation.

The design of the MAR system allows for different deployments of the system. There are three different deployments that can occur including:

- The MAR components remain on the heavy lift vessel and provide MAR support;
- The MAR components are offloaded and moored to the heavy lift vessel to provide dry dock space; and
- The MAR Components are offloaded to allow the heavy lift vessel to transport other material.

The situation where the MAR components remain on the heavy lift vessel can occur no matter what size ship requires MAR. A representation of the arrangement of the MAR system for this case can be seen below in Figure 21. The heavy lift vessel will position itself next to the damaged ship, offload the crane to allow for transportation of materials to and from the damaged ship, and begin the MAR operation.

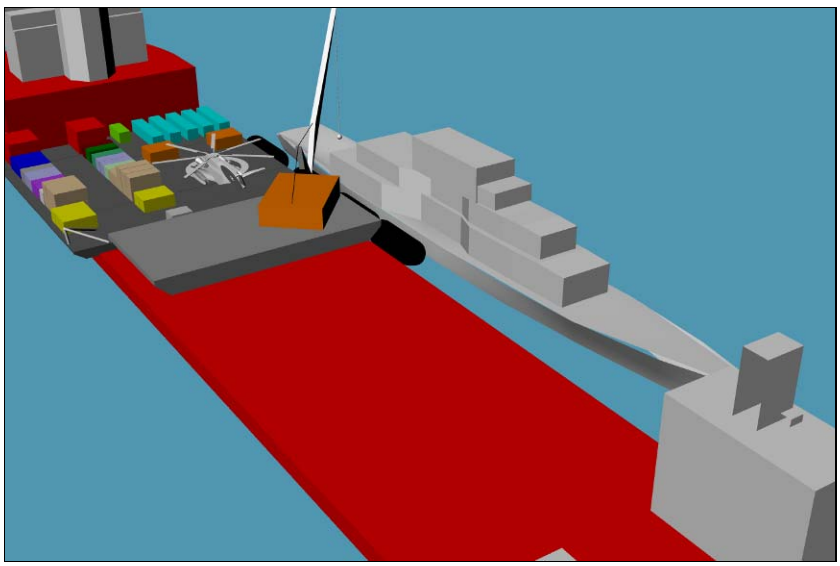

Figure 21: The MAR components remain on the vessel and provide MAR support

The next situation involves using the heavy lift vessel as a dry dock and offloading the MAR system. In this case, the MAR system would be moored to the side of the heavy lift vehicle with a ramp to allow for forklift transport of supplies to and from the damaged ship. The barge crane would be located next to the MAR system and would provide an additional method of transporting materials to and from the damaged ship. A representation of this situation can be seen on the following page in Figure 22.

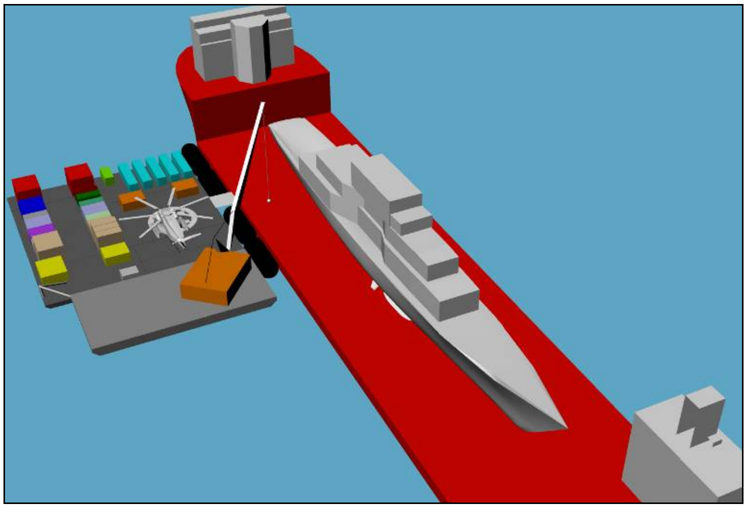

Figure 22: The MAR components are offloaded to provide dry dock space

The third situation involves using the heavy lift vessel to transport the MAR system to the damaged ship and then allowing the heavy lift vessel to depart and perform other duties. The MAR system would be moored to the damaged ship and the barge crane would act as a transfer point of materials to and from the damaged ship. Once the operation is complete, the heavy lift ship would return and transport the MAR system back to its origin. A representation of this situation can be seen below in Figure 23.

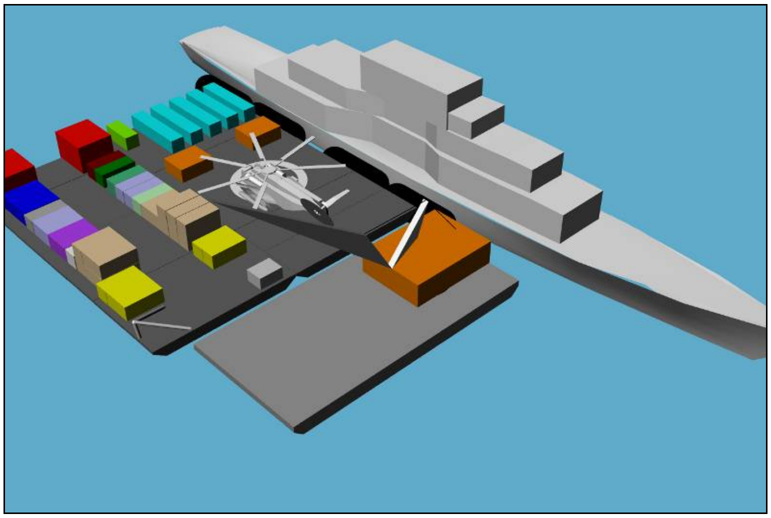

Figure 23: The MAR Components are offloaded to allow the vessel to transport

CombiDock

The next total ship model is based on the heavy lift ship CombiDock. The dimensions of this ship can be found in Table 1. There are several advantages of using a heavy lift ship similar to the CombiDock as an MAR staging vessel. The first advantage is that the CombiDock has large sea walls that would protect the MAR personnel from the elements while performing their duties. Another advantage is that the CombiDock has three cranes

that can be used in place of the crane barge used in the MV Black Marlin system. One of the disadvantages of the CombiDock is that it does not have as much open deck space as the MV Black Marlin. However, the ship does have liquid storage tanks that can store POL and potable water. As a result, deck space that would be used to store these materials can be used in other ways.

The arrangement of the MAR system components using the CombiDock heavy lift ship is very similar to the arrangement on the MV Black Marlin. MAR systems that require access to each other are located next to each other as on the MV Black Marlin, the only difference being the physical arrangement of the MCS platforms that are built on. The MCS platforms are arranged lengthwise instead of width wise as with the MV Blue Marlin because the CombiDock ship as a recessed deck with walls on either side. These walls do not allow for the MCS units to hangover the side of the ship as they did with the MV Blue Marlin. A representation of the configuration of the MAR system within the CombiDock storage area can be seen below in Figure 24.

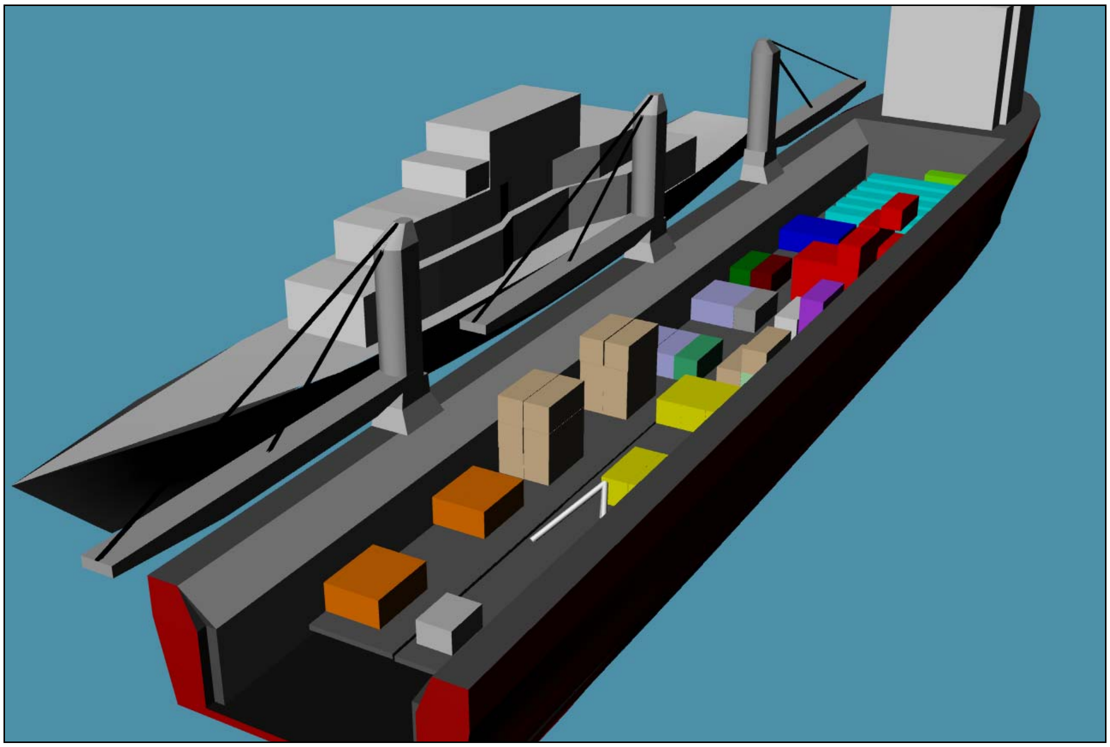

Figure 24: Arrangement of MAR system on CombiDock heavy lift vessel

As with the MV Blue Marlin, the arrangement of the MAR systems is not permanent and can be adjusted based on the type of MAR mission. The CombiDock can serve as a dry dock for larger ships. In this case, the MAR systems would be moored to the outside of the CombiDock and the heavy lift ship's cranes would act as a transfer method of material between the heavy lift ship and MAR system. However, unlike the MV Blue Marlin, there is not enough space on the CombiDock to allow for transport of a barge crane, so if crane access is necessary the CombiDock must remain in the area of the MAR operation.

Conclusions

The purpose of this study is to research and develop the use of commercially available heavy lift vessels for mission support applications. The concept is to use commercially available heavy lift vessels to transport material and equipment to perform a specific function without building a ship dedicated to that specific function. This study focuses on the use of heavy lift ships as marine maintenance and repair platforms. However, due to the modular design of the systems using ISO containers, MCS units or barges, and equipment currently stored by the Navy for emergency salvage applications; this concept can be adapted to a wide variety of situations. The important aspect of this design is its adaptability to different heavy lift ships as well as to different missions. The design does not require the use of a specific heavy lift ship or a specifically designed heavy lift ship and can provide the functionality that in the past required several specifically designed ships. The ultimate outcome of this design is that the Navy will be able to respond to a variety of situations, whether maintenance and repair missions or disaster relief operations, without designing specific ships for each of these different functions.

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Appendix A Acronym List

The following acronyms appear in this study. They are listed in order of appearance.

MAR	Maintenance and Repair
USACE	United States Army Corps of Engineers
MCS	Mobile Causeway System
IMCS	Intermediate Mobile Causeway Sections
MT	Metric Ton
BFIMA	Battle Force Intermediate Maintenance Activity
ESSM	Emergency Ship Salvage Material
LWDS	Light Weight Dive System
POL	Petroleum, Oil, Lubricants

Appendix B MAR System Requirements

Designated Area/Function	Services Provided	Equipment
Machine Shop	Part Fabrication Air Compressor Repair A/C and Refrigeration Repair Boiler Repair Pump Repair Diesel Engine Repair Electric Motor Repair GRP (Small Boat Repair) HX, Coolers, Distilling Plants Repair Machinery Shaft Alignment Oxygen-Nitrogen Producer Repair Structural Repair Steel Fabrication Sheet Metal Repair/Fabrication Piping Fabrication and Repair Electric Motor Repair Flex Hose Repair Rubber and Plastic Repair Valve Repair Rigging Repair Welding	20 ft ISO Containers Mill Lathe Band Saw Plasma Cutter Hydraulic Press Drill Press Welding Material
Electrical Shop	Electronics Repair Electronics Test Lab Electric Equipment Repair	20 ft ISO Containers
Composite Shop	Composite Fabrication/Repair	20 ft ISO Containers Hot Bond Unit Compressed Air Vacuum Pump Power Supply Mold Heater Blankets
Material Storage	Bulk Steel Angle/T-Steel Food/Water Composites Timber/Wood Lubricants Paint Fork Lift Operations Concrete	20 ft ISO Containers

Housing/ Accommodations	House Maintenance Crew Liquid/Solid Waste Treatment Bathroom/Shower Facilities	20 ft ISO Containers
Helicopter Pad	Deliver Supplies/Crew	
Crane	Crane for Transport of Supplies	Crane Barge
Ship Salvage	Underwater Divining/Welding Water Purification De-Flooding Lighting Compressed Air	Welding Equipment Salvage Bag Reverse Osmosis Water Purification Unit Submersible Pumping System Jet Pump System Lighting System 600 CFM Air Compressor
Pollution Control	Hazardous Material Containment Low Pressure Fenders Hazardous Material Storage Fire Fighting	Oil Containment Boom Portable Fire Fighting Low Pressure Fenders Command Van 290k-gallon Storage Bladders
Additional Power	Additional Power	30 kW Diesel Generator

Appendix C Weight and Space Estimate Excel Sheet

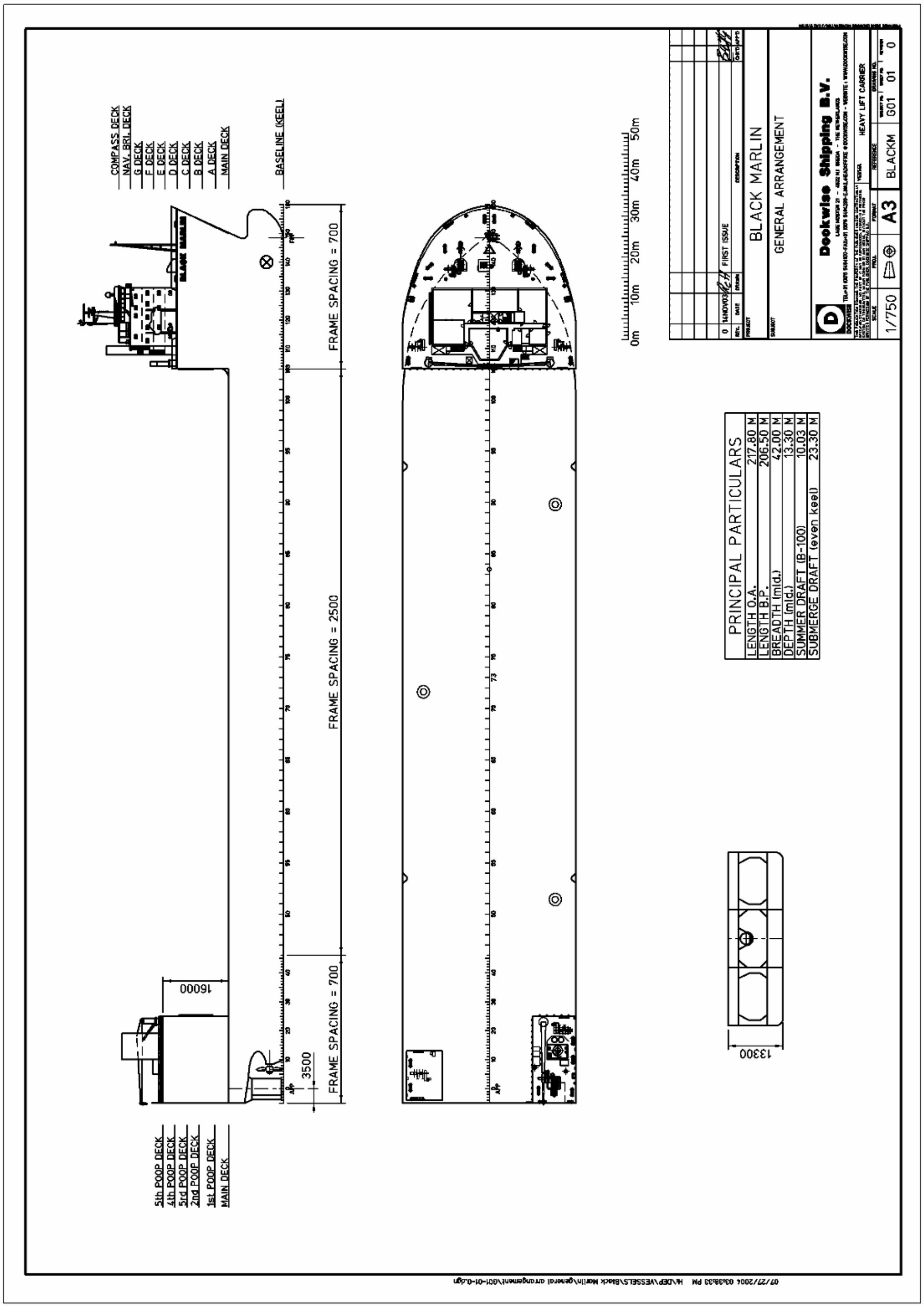
Designated Area/ Function	General Equipment	Qty	Length (m)	Width (m)	Height (m)	Deck Space Required (m^2)	Weight (kg)	Weight (mt)	Total Deck Space (m^2)	Total Weight (mt)	Estimated # of 20 ft ISO
Underwater Engineering-Diving	Control Console	1	0.4318	0.7874	0.8382	0.339999	68.04	0.06804	0.3399993	0.06804	0.022873264
	Diesel Compressor	1	1.016	1.2192	1.6764	1.238707	294.84	0.29484	1.2387072	0.29484	0.083333333
	Flask Rack	1	0.6096	1.016	1.1684	0.619354	90.72	0.09072	0.6193536	0.09072	0.041666667
	Roof Rack	1	0.2794	1.016	1.1684	0.28387	22.68	0.02268	0.2838704	0.02268	0.019097222
	Volume Tank	1	1.1684	0.7366	0.7122	0.860643	113.4	0.1134	0.8606434	0.1134	0.057899306
									Total	0.58968	1
Housing*	Personnel Bunk	2	12.192	2.4384	2.4384	29.72897	2449.399	2.449399	59.457946	4.898798	2
	Waste Water Treatment	1	12.192	2.4384	2.4384	29.72897	34473.02	34.47302	29.728973	34.47302	1
	Solid Waste Treatment	1	12.192	2.4384	2.4384	29.72897	34473.02	34.47302	29.728973	34.47302	1
	Shower/ Toilet Units	1	12.192	2.4384	2.4384	29.72897	11884.06	11.88406	29.728973	11.88406	1
									Total	85.7289	5
Communication	Communications System	1	2.7432	2.4384	2.4384	6.689019	3120.72	3.12072	6.6890189	3.12072	0.45
									Total	3.12072	1
Ship Salvage	Welding Area	1	2.1082	0.8128	1.4986	1.713545	1312.7	1.3127	1.713545	1.3127	0.115277778
	Salvage Bag	1	1.2446	1.0414	1.0668	1.296126	205.2	0.2052	1.2961264	0.2052	0.087196181
	Reverse Osmosis Water Purification Unit	1	4.572	2.4384	2.4384	11.14836	6209.68	6.20968	11.148365	6.20968	0.75

	Submersible Pumping System	1	2.1082	0.8382	1.3208	1.767093	1451.5	1.4515	1.7670932	1.4515	0.118880208
	Jet Pump System	1	2.794	0.9652	1.9558	2.696769	2018.49	2.01849	2.6967688	2.01849	0.181423611
	Lighting System	1	1.9558	1.4224	1.4478	2.78193	952.54	0.95254	2.7819299	0.95254	0.187152778
	600 CFM Air Compressor System	1	4.445	1.9558	2.3368	8.693531	3030	3.03	8.693531	3.03	0.584852431
									Total	15.18011	3
Polution Control	Oil Containment Boom	1	6.096	2.4384	2.4384	14.86449	12473.79	12.47379	14.864486	12.47379	1
	Portable Fire Fighting	1	6.096	2.4384	2.4384	14.86449	10378.19	10.37819	14.864486	10.37819	1
	Low Pressure Fenders	1	3.3528	2.4384	1.2192	8.175468	2326.93	2.32693	8.1754675	2.32693	0.55
	Command Van	1	6.096	2.4384	2.4384	14.86449	4109.55	4.10955	14.864486	4.10955	1
	290k-Gallon Storage Bladders	1	7.5184	2.4384	2.4384	18.33287	10727.5	10.7275	18.332867	10.7275	1.233333333
									Total	40.01596	5
Machine Shop	Mill	1	2.4732	2.4732	x	6.116718	680.39	0.68039	6.1167182	0.68039	0.411498795
	Lathe	1	2.5	1.5	x	3.75	453.6	0.4536	3.75	0.4536	0.25227915
	Band Saw	1	2.6764	1.7874	x	4.783797	453.6	0.4536	4.7837974	0.4536	0.321827289
	Plasma Cutter	1	1.25	1.25	x	1.5625	22.68	0.02268	1.5625	0.02268	0.105116313
	Hydraulic Press	1	1.7112	2.0414	x	3.493244	453.6	0.4536	3.4932437	0.4536	0.235006013
	Drill Press	1	1.3048	1.5334	x	2.00078	226.8	0.2268	2.0007803	0.2268	0.134601376
	Welding Generator, Cutting Torch, Cables	1	2	2	1	4	45.36	0.04536	4	0.04536	0.26909776
	Rigging Van	1	6.096	2.4384	2.4384	14.86449	7520	7.52	14.864486	7.52	1
									Total	9.85603	3
Structural Shop	see machine shop	x	x	x	x	x	x	x	x	x	x
									Total	x	x
Pipe Shop	see machine shop	x	x	x	x	x	x	x	x	x	x

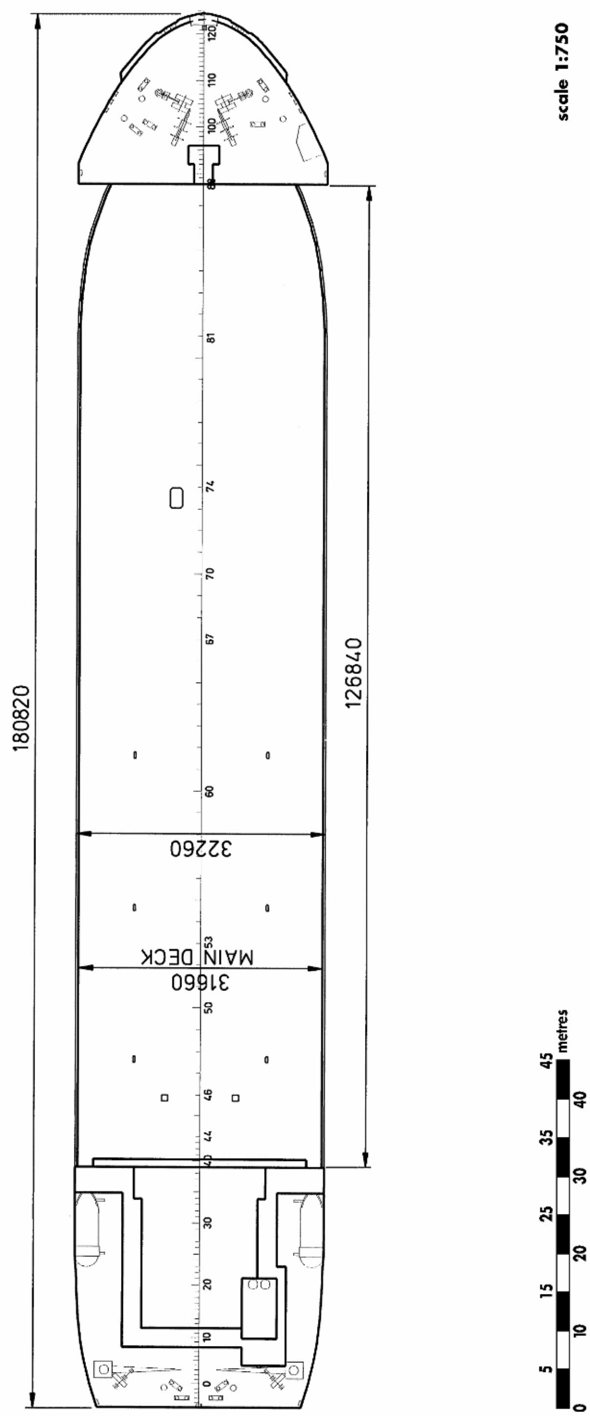
									Total	x	x
Electrical Shop		1	6.096	2.4384	2.4384	14.86449		0	14.864486	0	1
									Total	0	1
Material Storage	Bulk Steel	3	6.096	2.4384	0.0254	14.86449	3300	3.3	44.593459	9.9	3
	Food/Water	1	x	x	x	174.6108	40386.43	40.38643	174.61077	40.38643	12
	Composites	1	6.096	2.4384	2.4384	14.86449	3300	3.3	14.864486	3.3	1
	Timber 1	60	1	0.9114	0.6096	0.9114	277.79472	0.2777947	54.684	16.66768	4
	Timber 2	3	153.924	0.3048	0.3048	46.91604	7150.00376	7.1500038	140.74811	21.45001	10
	Lubricants	1	x	x	x	14.86449	1400	1.4	14.864486	1.4	1
	Paint	1	x	x	x	8.9		0.634	8.9	0.634	1
	Fork Lift (4 MT capacity)	5	2.54	1.17	2.09	2.9718	2000	2	14.859	10	1
	Concrete	1	6.096	2.4384	2.4384	14.86449	10000	10	14.864486	10	1
	30 kW Diesel Generator	5	2.2098	0.9906	1.4986	2.189028	1678.29	1.67829	10.945139	8.39145	1
	Pipes	1	6.096	2.4384	2.4384	14.86449	5000	5	14.864486	5	1
									Total	103.7381	36
Helicopter Pad	NA	1	30	30	x	900	33000	33	900	33	x
									Total	33	x
Crane Barge	NA	1	42.672	21.336	x	910.4498	1656156.46	1656.1565	910.44979	1656.156	x
									Total	1656.156	x
Composite Shop	Hot bond unit, compressed air, vaccuum pump, power supply, mold, heater blankets	1	6.096	2.4384	2.4384	14.86449	9706.88	9.70688	14.864486	9.70688	1
									Total	9.70688	1
MCS	MCS	10	24.384	7.3152	x	178.3738	66000	66	1783.7384	660	x
									Total	660	x
									TOTAL	**2617.09**	**56**

* Housing/Accommodations are provided in 40 ft ISO containers instead of 20 ft ISO containers.

Appendix D M. V. Black Marlin



Appendix E M. V. Swan



Appendix F CombiDock